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Fabrication of Ferrite/Permalloy Laminated Core by Spark Plasma Sintering

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Abstract - Laminated core composed of ferrite and Permalloy layers were prepared by Spark-Plasma-Sintering (SPS) method. The ferrite/Permalloy laminated core showed high bonding strength, higher saturation magnetic flux density than ferrite itself and high permeability at high frequencies. This laminated core is one of the promising candidates for high performance new magnetic core used in electronic magnetic devices, such as inductors, transformers and magnetic heads for card reader.

I. Introduction

Recently, miniaturization of portable electronic sets is remarkably progressing and their operating frequency becomes higher. Higher frequency operation and higher performances are strongly required in the magnetic devices such as inductors and transformer used in the electronic sets. Also, in the field of the magnetic card reader, both higher frequency operation and high recording ability on high coercivity media are desired. Therefore, development of a new magnetic head core material with large saturation flux density (Bs) and high permeability at high frequencies is strongly required.

In this study, to meet this demand, a laminated core composed of ferrite and Permalloy was developed and its novel fabrication method using Spark-Plasma-Sintering (SPS) method was proposed.

II. Structure and Fabrication Method of Ferrite/Permalloy Laminated Core

The soft magnetic materials used as magnetic core are classified to metal system and ferrite (oxide) system. The metallic magnetic materials have high Bs and high permeability. However, in the high frequencies, the permeability decreases because of the Eddy current effect originated from low electric resistance in the metallic materials. On the other hand, in the ferrite magnetic materials, Eddy current is essentially small because their electric resistance is sufficiently high. However, Bs is small in the oxide magnetic materials. Hence, it is difficult to satisfy the requirements of high Bs and high permeability at high frequencies using one kind of magnetic material. The magnetic core in which high Bs metallic magnetic ribbons and electrically highly resistive ferrite layer are laminated may be one of the candidates satisfying high Bs and superior soft magnetic properties at high frequencies suppressing Eddy current loss. Sufficiently high bonding strength at the interface of the lamination is needed from the viewpoint of actual machining of the core. In this study, the SPS method was introduced to fabricate the ferrite/Permalloy laminated core. In SPS, starting materials are heated up and sintered by Jule heat with the assist of plasma generated by DC pulse current under the uni-axial pressing.[1] The SPS method has advantages of lower temperature and shorter time sintering processing compared with conventional sintering method.

III. Experimental

The SPS-511 apparatus produced by IZUMI TECH. CO. LTD. was used for the fabrication of the ferrite/Permalloy laminated core. The 45 Permalloy ribbons (Bs=13.4 kG, Hc=8.25 Oe) were used as metallic magnetic material. Mn-Zn ferrite powder (Fe_2O_3 : MnO : ZnO = 53.5 : 32.2 : 14.3 (mol%)) made by TODA KOGYO CORP. were used as ferrite layer. At first, the Permalloy ribbon was put in a conductive graphite die with an inner diameter of 15 mm. Mn-Zn ferrite powder was spread on it. This operation was repeated in several times. Finally, the Permalloy ribbon was put on the top of lamination. This laminated specimen was pressed by conductive punches from top and bottom sides. This mold composed of the die and punches was set in a vacuum chamber. With pressing specimen at a pressure of 0.3 to 0.9 tf/cm^2, the specimen was heated up to 1000℃ at rising temperature rate of 100 ℃/min with supplying DC on-off current through the graphite punches. The specimen was held at 1000℃ for

2 to 10 minutes to sinter, where the time is called "holding time". After sintering, pressure was released and specimen was gradually cooled down to room temperature.

Magnetic properties of the laminated core were measured with a VSM and an Hc meter. Measurement of bonding strength of the lamination was done by Sebastian method. SEM was used to observe the cross section of laminated core. Element analysis was carried out by EPMA. Relative permeability of the laminated cores was calculated from inductance measured with an LCZ meter.

IV. RESULTS AND DISCUSSION

The ferrite/Permalloy laminated core was prepared using SPS method. A cross sectional SEM image of the laminated core using 0.1mm thick six Permalloy ribbons is shown in figure 1. This laminated core was prepared under the sintering conditions : holding time of 10 minutes and the welding pressure of 0.3 tf/cm^2. It was found that the Permalloy layers were sandwiched by the ferrite layers with uniform spacing. The fabricated laminated core was firmly bonded. Bonding strength of the laminated core was measured by Sebastian method using a jig called stud. The laminated core specimen composed of ferrite/Permalloy/ferrite was prepared for this measurement. Cross sectional SEM image of the laminated core after bonding strength test was shown in figure 2. White broken circle shows broken position. The laminated core specimen was broken down not at the interface between Permalloy and ferrite layers but in ferrite layer when the tensile strength forced through the stud was reached to 102 kgf/cm^2. This result shows that the bonding strength between Permalloy and ferrite interface exceeds 102 kgf/cm^2.

Figure 3 shows the Ni element distribution in the Permalloy/ferrite/Permalloy/ferrite/Permalloy core, which was observed using EPMA. Ni element was apparently diffused from the Permalloy layer to the ferrite layer. It was supposed that the large bonding strength was originated from the diffusion of Ni element at the ferrite/Permalloy interface.

Influence of sintering condition on magnetic properties of the laminated core was examined. In figure 4, Bs and Hc of the laminated core were plotted against the welding pressure. In this laminated core, 0.05mm thick three permalloy ribbons and ferrite powder (0.3g for each ferrite layer) were used. Hc decreased and Bs increased with increasing welding pressure.

Figure 5 shows the holding time dependence of Bs and Hc of laminated core. In this laminated core, 0.5mm thick three Permalloy ribbons and ferrite powder (0.1g per

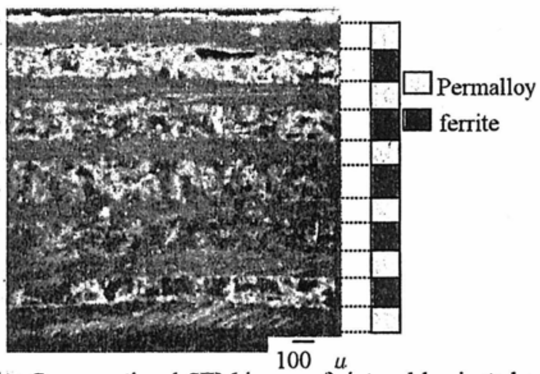

Fig.1 Cross sectional SEM image of sintered laminated core sample. (Permalloy layer : 0.1 mm^t × 6 layers)

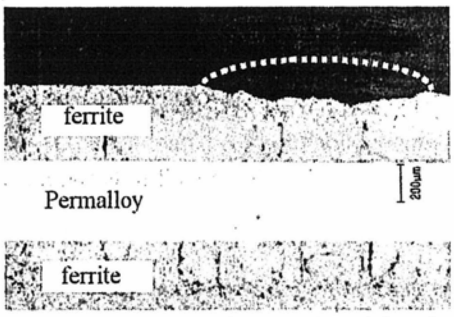

Fig.2 Cross sectional SEM image of sample after bonding strength test. (White broken circle shows broken position.)

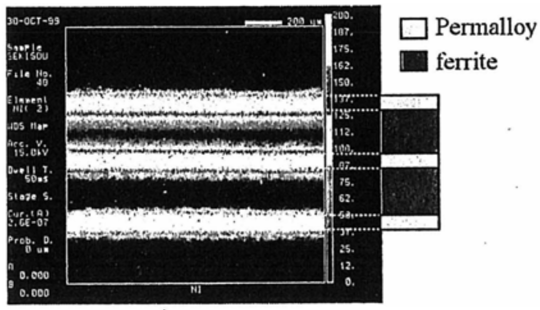

Fig.3 Ni element mapping in laminated core.

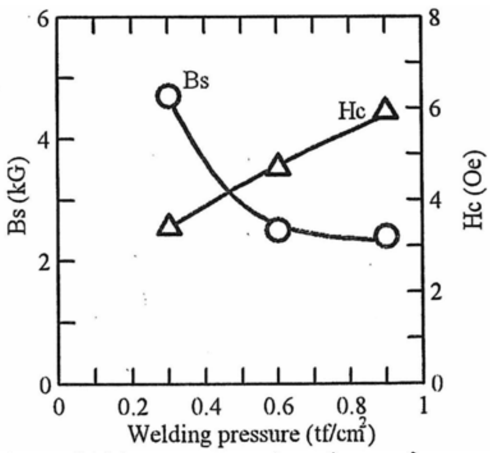

Fig.4 Welding pressure dependence of magnetic properties of laminated core.

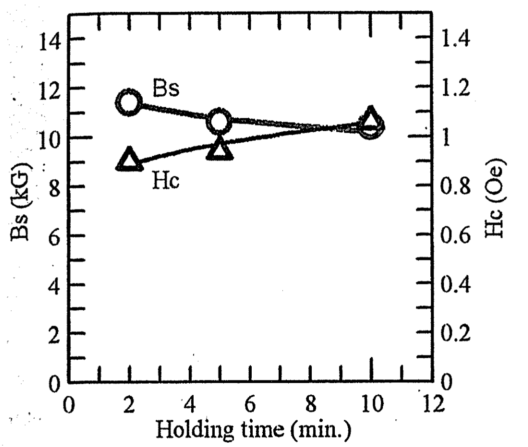

Fig.5 Holding time dependence of magnetic properties.

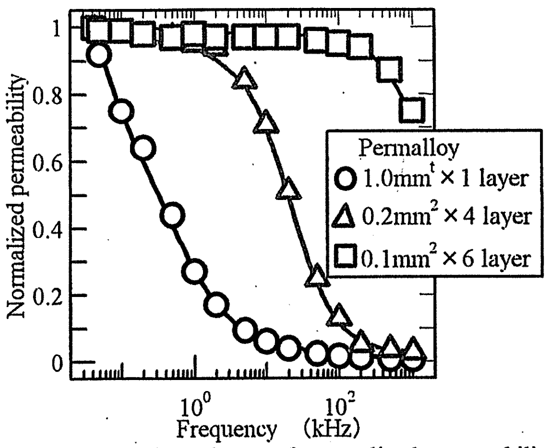

Fig.6 Frequency dependence of normalized permeability of laminated samples. (Permeability is normalized at 50 Hz.)

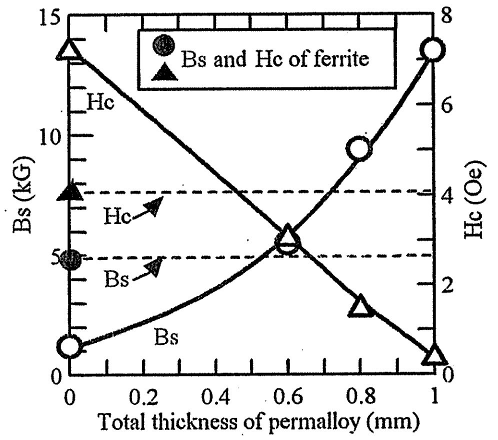

Fig.7 Dependence of Hc and Bs on total thickness of Permalloy in 1mm^t laminated core sample. (Total thickness of 0mm corresponds to Mn-Zn ferrite single layer core, and total thickness of 1mm corresponds to Permalloy single layer core.)

each layer) were used. Hc decreased and Bs increased as holding time became longer.

The advantage of suppression of Eddy current loss by laminating permalloy ribbons with ferrite layers was examined. Figure 6 shows frequency dependence of permeability of the several cores. Permeability was normalized by the value at low frequency. Three samples with different thickness and number of Permalloy layer were prepared. For the non-laminated core which is composed only Permalloy ribbons (○), permeability abruptly decreased because of Eddy current loss as the frequency became high. However, for the laminated cores, high permeability was maintained even at high frequencies (△,□), and thinner Permalloy layer is more effective to improve high frequency characteristics.

Dependence of Bs and Hc of the laminated core on total thickness of Permalloy layer was shown in figure 7. Solid circle and solid triangle are for the core composed of ferrite layer only. In the region where total Permalloy thickness occupied over 50% of the core, low Hc and high Bs exceeding ferrite core were obtained. On the other hand, in the Permalloy thickness region under 50%, Bs became smaller and Hc becomes higher than the specimen fabricated with ferrite only. This is because the magnetic properties of ferrite layer were degraded because of Ni diffusion from Permalloy layer. We have already confirmed that if the metallic magnetic materials without Ni, for example Sendust, was used instead of Permalloy ribbon, Bs of the laminated core did not become lower than the core composed of ferrite only.

V. SUMMARY

The soft magnetic cores in which Permalloy ribbons and Mn-Zn ferrite layer were laminated were fabricated by SPS method. The core showed strong bonding strength, higher saturation magnetic flux density than ferrite itself, and high permeability at high frequencies. Therefore, this new magnetic core is a promising candidate applicable to high frequency magnetic devices.

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